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Y-12

OAK RIDGE
Y-12
PLANT

MARTIN MARIETTA

OAK RIDGE Y-12 PLANT
HISTORICAL URANIUM AND RADIONUCLIDE RELEASE REPORT

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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Y/DG-17723

OAK RIDGE Y-12 PLANT
HISTORICAL URANIUM AND RADIONUCLIDE RELEASE REPORT

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
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1. SUMMARY

Maximum credible quantities of uranium and radionuclides from the Y-12 Plant discharged to the air and water and buried in disposal sites from 1944 through 1984 are listed in the following table.

Discharged	Material	Curies	Pounds	Kilograms	Period
Air	Uranium	13	12,700	5,800	1944-1984
Water	Uranium	114	396,500	180,000	1944-1984
	Thorium	<1		6,000	1954-1984
Buried	Uranium	6500	35,000,000	16,000,000	1944-1984
	U-233	19	4	2	1967-1968
	Thorium	18	374,000	170,000	1947-1984
	Technetium	54	7	3	1953-1984
	Neptunium	2	5	2	1953-1984

The amount of uranium discharged to the air and water is larger than was shown in a June 1985 report, *Y-12 Plant Uranium Discharges* (Y/TS-105, Rev. 1), due to several uranium releases identified between 1944 and 1954. The June 1985 report did not pursue these years. Also, additional accountability uranium release records are included in this report that were not included in the previous report.

Considerably less uranium solid waste is buried at the Y-12 Plant than is shown in the June 1985 report. This difference is due to assumptions about the isotopic compositions and material homogeneity in data provided to generate the Solid Waste Information Management System (SWIMS) reports on which the June 1985 report was based. The figures in this report reflect a more accurate accounting of the actual material disposed.

2. INTRODUCTION

2.1 PURPOSE

This report contains all known uranium and other radionuclide discharges from the Y-12 Plant. The information has been compiled from routine accountability reports, environmental and radiological monitoring data, estimates of discards (using calculational methods where firm data was not available), and any other means appropriate to locating information on discards.

2.2 SCOPE

In addition to uranium discard information, which constitutes by far the majority of the Y-12 discards, this report includes data on thorium, U-233, technetium, neptunium, and other very small quantities of radionuclides (plutonium, cesium, cobalt, ruthenium, niobium) in receipts of special nuclear material—particularly the uranyl nitrate solutions from the Savannah River Plant (SRP) and uranium oxide from the Idaho Chemical Processing Plant.

2.3 Y-12 PLANT HISTORICAL BACKGROUND

The Oak Ridge Y-12 Plant was built for the U.S. Army Corps of Engineers in 1943 as part of the Manhattan Project. The original mission of the plant was to separate the fissile isotope of uranium (U-235) from natural uranium by the electromagnetic process. This effort, involving approximately 1200 electromagnetic separation units known as "calutrons," required an original capital investment of over $500 million and a peak operating force of 23,000 workers. Production of U-235 by the electromagnetic process was discontinued after World War II in favor of the more economical gaseous diffusion process. Since then, the plant has developed into a highly sophisticated manufacturing, development, and engineering organization.

The Y-12 Plant has four principal missions: (1) producing nuclear weapons components and supporting the Department of Energy's (DOE's) weapons design laboratories; (2) processing special materials; (3) supporting other Oak Ridge, Tennessee, and Paducah, Kentucky, installations; and (4) supporting other government agencies.

The Plant's primary mission is producing nuclear weapons components and subassemblies and providing support to DOE's weapons design laboratories. The major Y-12 production responsibilities involve the fabrication of various materials into components, the certification of the fabricated components, and the production of subassemblies from some of the components. Materials used typically include enriched uranium; depleted uranium and its alloys; tungsten-nickel-iron alloy; specialty steels; lead; some precious metals; and niobium, tantalum, and other refractory metals. Extensive facilities are available for recycling scrap bearing enriched uranium, lithium, and deuterium.

The Y-12 Plant is the country's primary production facility that routinely processes highly enriched uranium, and Y-12 personnel must constantly deal with its health, environmental, and national security implications. Special precautions and equipment are used to prevent criticality—an uncontrolled chain reaction in this fissile material.

As part of its primary mission, Y-12 also provides fabrication support to the DOE weapons design laboratories at Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and Sandia National Laboratories (SNL). For these laboratories, Y-12 produces components for design evaluation and for most of the test devices fired underground at the Nevada Test Site.

Y-12's second mission is the processing of special materials. Enriched uranium from the Savannah River Plant and the Idaho Chemical Processing Plant (in the form of uranyl nitrate solution and UO_3) is processed to uranium metal. Enriched uranium metal and compounds of enriched uranium are also provided to other agencies.

The third principal mission is to provide support to other Oak Ridge and Paducah installations. Approximately 1000 Oak Ridge National Laboratory (ORNL) employees and guests, for whom Y-12 supplies housekeeping, maintenance, and utility services, are located on the plant site. In addition, Y-12 provides manufacturing support for the K-25 site and the Paducah Gaseous Diffusion Plant (PGDP) when its capabilities are required and its production schedules permit.

As its fourth principal mission, Y-12 provides support and assistance to other government agencies whenever time or technology considerations warrant the utilization of Y-12 capabilities.

2.4 DATA APPLICABLE TO URANIUM EMISSIONS

Data for the period 1954 to 1984 pertaining to emissions or disposals (Tables 2, 7, and 13) were obtained from Y-12 Plant accountability records, the DOE Effluent Information System Radioactivity Summary Report, and SWIMS. Comparable data was not as complete between 1944 and 1954, but enough data was uncovered in Health Physics reports (and others) to make a considerable impact in the final estimate of uranium releases since 1944.

3. Y-12 PLANT AIR URANIUM EMISSION DATA

Of approximately 350 process exhaust stacks at Y-12, over 100 serve operations with a potential for generating airborne radioactive uranium. Today there are approximately 65 stacks for depleted uranium operations and approximately 51 stacks for enriched uranium operations. Thirty-nine of the depleted uranium stacks and 43 of the enriched uranium stacks are equipped with emission control systems. These controls range from simple fabric filters and bag houses to combination systems, including high-efficiency particulate air (HEPA) filters. Presently, accountability stack monitoring is performed on 36 of the 51 enriched process stacks and on one of the 65 depleted uranium stacks.

Stack sampling is currently performed using multiport probes inserted into selected ducts or stacks. Samples are withdrawn continuously. Filter sample papers (Whatman 41) are usually replaced daily, and samples are analyzed for gross alpha activity and converted to grams of uranium discharge per 24 h. Weekly, monthly, and annual discharge is documented. From 1976 to 1982 the annual discharge per year was sent to EG&G at Idaho Falls, Idaho, where it was entered into the *Radioactive Summary Report,* or "Radioactive Effluent Report," as it is commonly referred to in Y-12.

Y-12 Airborne uranium emissions data are shown in Tables 1 through 5. Table 1 shows enriched, depleted, and normal uranium as estimated or measured. Table 2 shows uranium discharges by fiscal year in kilograms associated with calculated values for curies. Table 3 summarizes airborne emissions for 1944 through 1984. Table 4 lists annual average concentration data from air monitoring stations. Table 5 shows the measured values as percentage of the applicable DOE concentration guides.

Table 1 summarizes the airborne uranium emissions from 1944 through 1984. The basis for each columnar entry follows.

Column ME (measured enriched uranium) includes 114 kg taken from the Radioactive Effluent Report. Also included is 42 kg of uranium due to accidental uranium releases from 1956 through 1959. These data were obtained from uranium accountability records.[1]

Column EE (estimated enriched uranium) indicates an addition to the Radioactive Effluent Report for uranium off-gas release from 1954 through 1964 in an enriched gas stack. A uranium-release detection instrument monitored the concentration of uranium release.[2] In 1983 a 1.9-kg deposit of enriched uranium was discovered in an enriched stack. Evidence indicated that this deposit occurred during a period of eight to ten years. An investigating committee determined that ten times that amount (19 kg) of uranium was probably released to the atmosphere.[3] The column totals approximately 22 kg of enriched uranium.

Column MD (measured depleted uranium) totals 226 kg taken from the Radioactive Effluent Report. Where appropriate, additional quantities were estimated from these values and are shown in column ED.

Column ED (estimated depleted uranium) is an addition to the Radioactive Effluent Report due to partial three- and six-month sample results. In 1965 the uranium release measurement was obtained for six months with a result of 35 kg uranium (see column MD). This quantity was also used as an estimate for the remaining six months of 1965 and is shown in column ED. Also, in 1970 the uranium release was measured for three months with a result of 12 kg (see column MD). An additional 36 kg of uranium was added to get the yearly estimate and is shown in column ED.

Column F-L ED (Fellers-Loden estimated depleted uranium)[4] is a result of the depleted stack survey. In order to update and expand the depleted stack sampling survey (only one of 61 stacks continually sampled now), 44 depleted uranium stacks were grab sampled for uranium release using a crude, semiquantitative technique. Results showed a plant emission level of 140 kg of uranium per year. On the basis of recent inspections of the various off-gas systems, filter deterioration probably occurred gradually over many years. Consequently, losses prior to 1984 were assumed to be linear with time over the life of each system. Actual plant losses could have been significantly less, but not likely more than the overall estimate. Of the 260 kg total released in 1985, a single exhaust contributed 120 kg. The total release was estimated at 3670 kg of depleted uranium. It is possible that values in this column may include the emissions shown in columns MD and ED, which would tend to make total estimates higher than actual.

Column HV-EN (heating and ventilation estimated normal uranium) was obtained from a special medical report[5] that dealt with the recovery of airborne uranium in several operating buildings. Issued in November 1945, it showed an estimated possible release of 102 kg of normal uranium during the electromagnetic operating days of 1945. The 1945 estimate was extrapolated over all the electromagnetic operating years, resulting in a total estimated release of 314 kg of normal uranium, though this possibly could have been a mixture of normal and enriched uranium.

Column HV-ED (heating and ventilation estimated depleted uranium) shows the possible discharge of uranium in the nonprocess heating and ventilation systems of the depleted uranium operating buildings. This is the first time this factor has been evaluated since the study of 1945. Average air alpha activity per minute, as well as the nonprocess H/V fan ventilation rates, was obtained for the years between 1964 and 1984. This indicates a possible discharge of 65 kg depleted uranium per year or a total of 1300 kg of depleted uranium for the 20-year study. With the limited number of facilities related to depleted uranium in the early years, this engineering estimate is felt reliable only for this 20-year period.

The total discharge to the air is estimated at 5800 kg (12,700 lbs) of uranium (Table 3).

Alpha activity measurements (principally uranium) at area air monitoring stations applicable to the Y-12 Plant have been reported since 1966. Beginning in 1975, samples at the air monitoring stations were evaluated to ensure that alpha activity measurements are equivalent

to uranium. Because of the geographic locations of stations HP-31, HP-32, HP-39, and new stations HP-40 and HP-41, the data collected from these stations are expected to be primarily influenced by emissions from the Y-12 Plant. Stations HP-55 and HP-37 are expected to be influenced by background conditions or uranium from sources other than the Y-12 Plant, such as coal-fired power plants. Table 4 lists annual average concentration data from the stations. Based on the data in Table 4, there is little increase in the alpha activity (uranium) in stations related to the Y-12 Plant relative to the background stations. Little correspondence is seen between emissions (Table 2) and airborne concentrations (Table 4), probably as a result of the low concentrations involved. Table 5 indicates the measured values as a percentage of the applicable DOE concentration guides.

The highest average sample concentration for gross alpha measurements was observed in 1966 at station HP-32. The value was 7×10^{-15} µCi/mL, which was 0.35% of the applicable concentration guide. New stations HP-40 and HP-41 show higher values for 1983 than do stations 31, 32, and 39. This is a result of placing the stations in locations more directly "downwind" of the Y-12 Plant and thus more strongly influenced by Y-12 Plant uranium emissions. Measurements at all stations related to the Y-12 Plant average approximately 0.03% of applicable concentration guides.

Table 4. Airborne uranium emissions

Year	A ~~ME~~ measured ~~ENR-U~~ (kg)	B ~~EE~~ estimated ENR-U (kg)	C ~~MD~~ measured ~~DEP-U~~ (kg)	D ED estimated DEP-U (kg)	E F-L ED estimated DEP-U (kg)	F ~~HV-EN~~ estimated NOR-U (kg)	G ~~HV-ED~~ est. ~~DEP-U~~ (kg)
1944						55	
1945						102	
1946						102	
1947						55	
1948							
1949							
1950							
1951							
1952							
1953					30		
1954		2			30		
1955		2			30		
1956	11.16	2			30		
1957	9.16	2			30		
1958	8.95	2			30		
1959	28.53	2			90		
1960	7.11	2			90		
1961	7.11	2			100		
1962	7.90	2			90		
1963	11.06	2			90		
1964	9.48	2	68.49	0.027	90		
1965	6.32		35.14	0.05 35	140		65
1966	7.11				140		65
1967	7.11			0.05	140		65
1968	5.53				140		65
1969	5.53		12.00		140		65
1970	6.32		12.00	36	140		65
1971	0.79		84.38	69	140		65
1972	0.16		6.74		150		65
1973	0.16		0.71		140		65
1974	1.42		0.67		140		65
1975	1.74		2.36		140		65
1976	1.74				140		65
1977	0.95				140		65
1978	0.16				140		65
1979	0.95				140		65
1980	2.53				150		65
1981	1.90				140		65
1982	1.74		0.14		140		65
1983	1.90		1.49		140		65
1984	1.54		2.01		260		65
	156[a]	22	220[a]	71	3670	314	1300

[a]Rounded to nearest kilogram.

Source: Griffith, 1987; Owings, 1986

Table 2. Y-12 Plant airborne uranium emissions

Year	Uranium[a] (Ci)	Uranium discharges (kg)
CY 1944	0.04	55
1945	0.07	102
1946	0.07	102
1947	0.04	55
1948	-	-
1949	-	-
1950	-	-
1951	-	-
FY 1952	-	-
1953	0.01	30
1954	0.14	32
1955	0.14	32
1956	0.83	43
1957	0.71	41
1958	0.71	41
1959	1.93	120
1960	0.60	99
1961	0.61	109
1962	0.66	100
1963	0.85	103
1964	0.76	170
1965	0.48	281
1966	0.51	212
1967	0.51	212
1968	0.45	211
1969	0.46	223
1970	0.47	259
1971	0.16	290
1972	0.08	222
1973	0.07	206
1974	0.13	207
1975	0.21	209
1976	0.20	207
1977	0.13	206
1978	0.07	205
1979	0.13	206
1980	0.28	218
1981	0.20	207
1982	0.20	207
1983	0.20	208
1984	0.25	329
	13.36	5759

[a]Conversion factors used in calculating the curie values: normal uranium, 1.49 x 10^6 g/Ci; depleted uranium, 2.78 x 10^6 g/Ci; enriched uranium, 1.58 x 10^4 g/Ci.

1985

1986

Table 3. Airborne uranium emission summary, 1944-1984

Measured enriched uranium (ref. 1)		156 kg
Measured depleted uranium		226 kg
Estimated:	enriched stack discharge (refs. 2,3)	22 kg
Estimated:	1965 and 1970 additional depleted uranium	71 kg
Estimated:	Fellers-Loden depleted uranium stack survey (ref. 4)	3670 kg
Estimated:	1944-1947 (normal uranium) (ref. 5)	314 kg
Estimated:	HV of depleted buildings (depleted uranium)	1300 kg
Total		5759 or rounded to 5800 kg (12,700 lbs)

Table 4. Y-12 Plant average uranium concentration data from area air monitoring stations

(average gross alpha, x 10^{-15} μCi/mL)

Year	Station[a]						
	HP-31	HP-32	HP-39	HP-40[b]	HP-41[b]	HP-37	HP-55
1966	6	7	6			4	3
1967	3	5	5			3	3
1968	2	2	2			2	1
1969	2	2	2			2	1
1970	1	3	1			1	1
1971	<1	<2	<1			<1	<1
1972	2	3	2			2	2
1973	1.7	2.6	1.8			1.4	1.9
1974	1.3	1.6	1.3			1.0	1.3
1975	1.0	1.4	1.2			1.0	1.1
1976	1.1	1.7	1.4			0.9	<0.9
1977	0.9	1.2	1.1			<1.0	0.9
1978	1.1	1.4	1.1			0.9	<0.9
1979	1.1	1.4	1.2			0.9	0.7
1980	0.9	1.1	0.9			0.9	1.5
1981	0.79	1.1	0.84			0.92	1.3
1982	0.92	1.1	0.86			0.78	1.1
1983	0.93	1.4	0.98	2.2	2.0	0.66	1.2
1984	c	1.4	0.82	2.9	3.0	0.84	1.3

[a]See Figs. 1 and 2 for locations of monitoring stations. Stations HP-31, 32, 39, 40, and 41 are related to the Y-12 Plant. Stations HP-37 and 55 are background stations.

[b]Stations HP-40 and 41 were started in 1983.

[c]Not available.

Table 5. Y-12 Plant average uranium concentration data from area air monitoring stations as percentage of applicable DOE concentration guides

Year	Station[a]							DOE concentration guide
	HP-31	HP-32	HP-39	HP-40[b]	HP-41[b]	HP-37	HP-55	(x 10^{-15} µCi/mL)[c]
1966	0.30	0.35	0.30			0.20	0.15	2000
1967	0.10	0.20	0.15			0.15	0.15	
1968	0.10	0.10	0.10			0.10	0.05	
1969	0.10	0.10	0.10			0.10	0.05	
1970	0.05	0.15	0.05			0.05	0.05	
1971	<0.05	<0.1	<0.05			<0.05	<0.05	
1972	0.1	0.15	0.1			0.1	0.1	
1973	0.04	0.07	0.05			0.04	0.05	4000
1974	0.03	0.04	0.03			0.03	0.03	
1975	0.03	0.04	0.03			0.03	0.03	
1976	0.03	0.04	0.04			0.02	<0.02	
1977	0.02	0.03	0.03			<0.03	0.02	
1978	0.03	0.04	0.03			0.02	<0.02	
1979	0.03	0.03	0.03			0.02	0.02	
1980	0.02	0.03	0.02			0.02	0.04	
1981	0.02	0.03	0.02			0.02	0.03	
1982	0.02	0.03	0.02			0.02	0.03	
1983	0.02	0.03	0.02	0.05	0.05	0.02	0.03	
1984	[d]	0.03	0.02	0.07	0.08	0.02	0.03	

[a]See Figs. 1 and 2 for locations of monitoring stations. Stations HP-31, 32, 40, and 41 are related to the Y-12 Plant. Stations HP-37 and 55 are background stations.

[b]Stations HP-40 and 41 were started in 1983.

[c]DOE concentration guides are listed in DOE Order 5480.1A, Attachment XI-1. The value of 4000 x 10^{-15} µCi/mL is the lowest limit specified for uranium. Prior to 1973 a different definition of the curie was used, resulting in a different concentration guide.

[d]Not available.

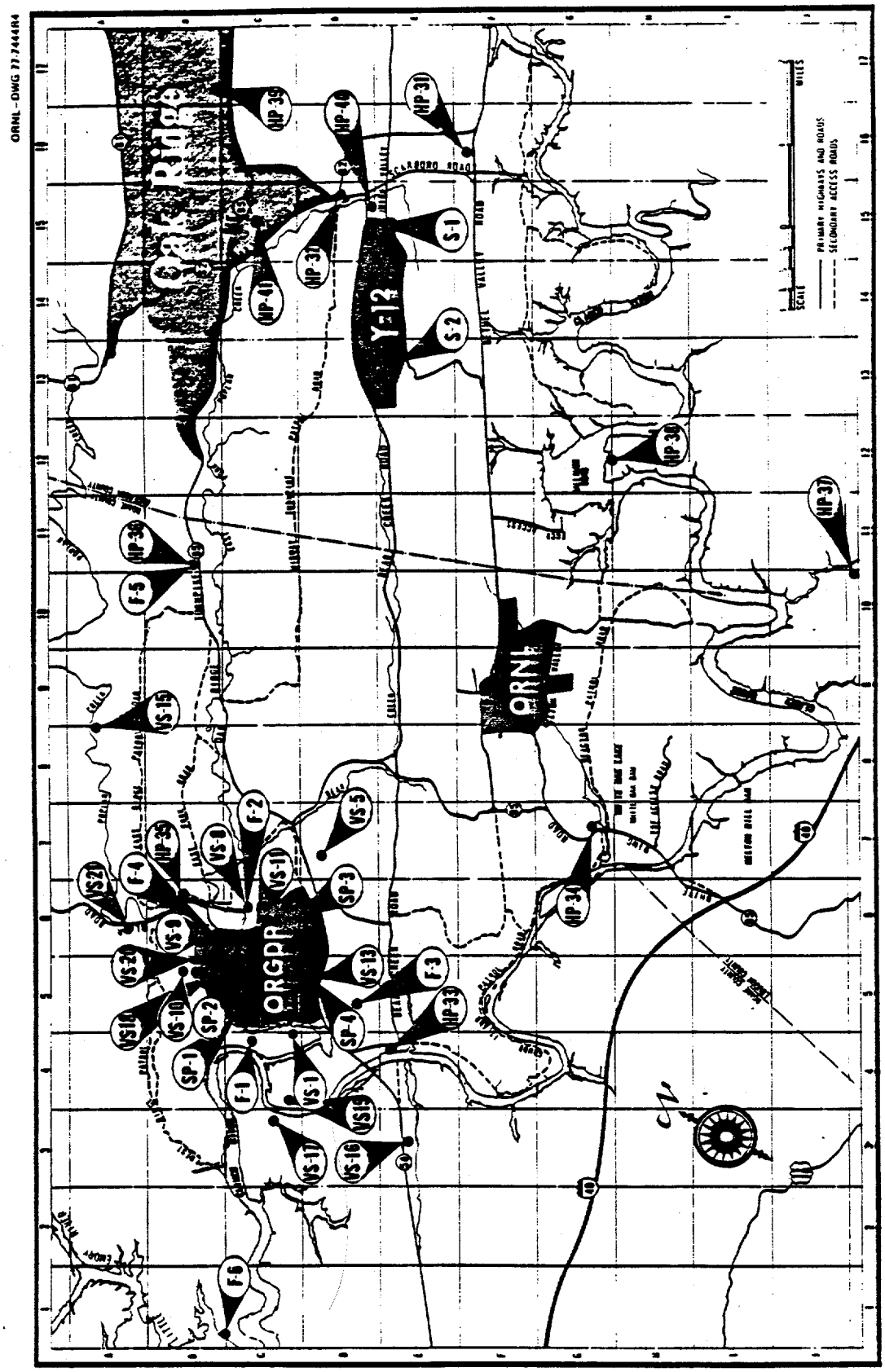

Fig. 1. Air, vegetation, and soil sampling locations.

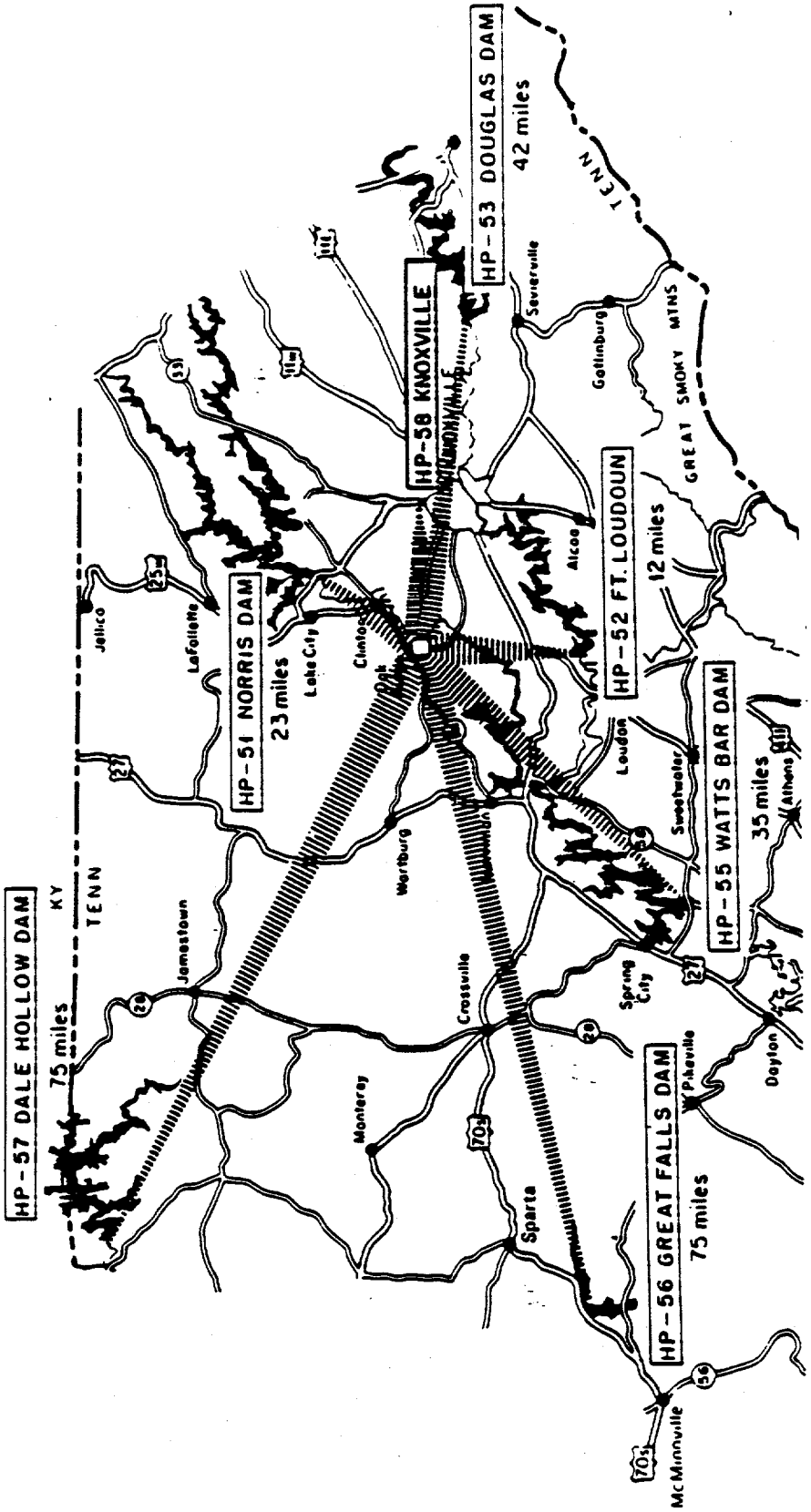

Fig. 2. Remote air monitoring locations.

4. Y-12 PLANT LIQUID EFFLUENT DATA

4.1 URANIUM

Until recent years, process water containing uranium for which collection and treatment facilities were not generally available was discharged to the storm sewer system and then into the East Fork Poplar Creek (EFPC). Surface water runoff from the main plant site also enters EFPC. Leakage from the S-3 Pond area and runoff from the Bear Creek Burial Ground and far west end of the site enter Bear Creek. The operation of the S-3 Ponds has been recently discontinued, and the material contained in them is being processed and discharged under the Y-12 Plant National Pollutant Discharge Elimination System (NPDES) permit. The plant's sanitary water is discharged to the City of Oak Ridge sanitary sewer system.

Flow-metering and sampling stations are located at the discharge from New Hope Pond to EFPC and on Bear Creek near Highway 95. Flow-proportional sampling is performed continuously at both locations. Samples are collected in stainless steel drums for a period of one week. At the end of the week the samples are mixed and an aliquot is withdrawn. These samples are analyzed by the plant laboratory. Results of discharge calculations are sent to EG&G, Idaho Falls, where they become the official data for the portion of the Radioactive Effluent Report concerning uranium discharge to the water system.

Liquid effluent data are shown in Tables 6 through 10. Table 6 shows normal, depleted, and enriched uranium as measured or estimated with reference to the operation or process where the discharge occurred. Table 7 shows uranium discharges by fiscal year in kilograms with calculated values for curies. Table 8 summarizes liquid discharges for 1944 through 1984. Table 9 lists annual concentration from the monitoring stations, and Table 10 indicates the proportion of the measured values to the applicable concentration guides.

Table 6 summarizes the discharge of uranium to surface water from 1944 through 1984. The basis for each columnar entry follows.

Column MN (measured normal uranium) shows the discharge of normal uranium to the water system for 1948, 1949, 1950, 1951, and 1953. The total uranium released was 1738 kg of normal uranium. These data were recently identified in monthly Health Physics reports from those periods.[6] Also, 3111 kg of normal uranium was discharged to the surface water for the years 1953-1967. These figures were obtained from accountability records.[7]

Column MD (measured depleted uranium) totals 128,755 kg for the years between 1954 and 1984 taken from the Radioactive Effluent Report. There is some normal and enriched uranium in this total.

Column EN (estimated normal uranium) shows that approximately 40,000 kg of uranium was discharged in 1944 and 1948. This release of uranium was primarily from the oxide feed handling buildings. This uranium could have been a mixture of normal and depleted assay material.

The excessive discharge of uranium to the storm sewers of one of the oxide feed handling buildings prompted sealing off the storm sewer inlet drain connections in 1945 to prevent additional discharge to the surface water.

Column ME (measured enriched uranium) shows the measured enriched uranium discharge from the operating buildings to the water system for the years 1949 through 1984. These uranium figures were obtained from routine accountability records.[9]

The total uranium discharge to surface water is estimated at 180,000 kg (396,500 lbs) of uranium (Table 8).

The 180,000 kg of uranium discharged to surface water does have some duplication because the 6620 kg of measured enriched uranium (from accountability records) discharged to the storm sewer between 1949 and 1984 and the 3111 kg of measured normal uranium (from accountability records) discharged to the storm sewer between 1953 and 1967. However, some uranium discharged from the plant never reached the EFPC or Bear Creek Monitoring Stations because it settled out in sediment in New Hope Pond, the S-3 ponds, or the upper portion of Bear Creek.

In 1973 New Hope Pond was dredged and the resultant sludge was transferred to a basin located on Chestnut Ridge above the pond. Core samples were taken in May 1983 from the 1973 deposits and from the recent deposits in New Hope Pond. The 1973 sludge deposit measures 2864 kg of uranium, and the uranium now in New Hope Pond is estimated at 4773 kg for a total of 7637 kg.

Core samples have also been taken at the S-3 Ponds, with initial results indicating a possible 2250 kg of uranium remaining in the sludge. The total uranium deposited in both the New Hope Pond (including the Chestnut Ridge study) and the S-3 Ponds comes to 9887 kg (21,750 lbs) of uranium.

Table 9 lists annual concentration data from the stations. Table 10 indicates the proportion of the measured values to the applicable concentration guides. Comparison of Table 7 (effluents) and Table 9 (concentrations) shows that as releases were reduced, the uranium concentration in the streams decreased.

The highest annual average sample concentration for uranium measurements in water was observed in 1972 at Station E-1. The value was 27 x 10^{-8} µCi/mL, which was 1.4% of the applicable DOE concentration guide. Station E-1 (in 1981) and Station B-1 (in 1982) had values that were 6.8% of a more recent and lower concentration guide of 60 x 10^{-8} µCi/mL.

Values for Stations E-1 and B-1 are much higher than the background station (C-3). Locations of stations are shown in Fig. 3. While the measured averages are well above background, they are significantly below the applicable DOE concentration guide at monitoring stations.

Table 6. Uranium effluent to water

Year	MN measured NOR-U (kg)	MD measured DEP-U (kg)	EN est. NOR-U (kg)	ME measured ENR-U (kg)
1944			33,000	
1945			7,000	
1946				
1947				
1948	155			
1949	409			45
1950	144			
1951	91			7
1952				3
1953	952			1
1954	59	1,058		1
1955	129	924		5
1956	1613	3,367		7
1957	11	8,419		18
1958	11	8,717		1291
1959	1171	7,674		1565
1960	21	6,780		3266
1961	26	2,980		58
1962	27	1,281		25
1963	5	1,222		21
1964	3	6,586		16
1965	14	8,806		32
1966	5	7,957		23
1967	3	15,198		16
1968		17,508		17
1969		4,172		17
1970		8,761		14
1971		3,531		15
1972		3,025		17
1973		1,103		16
1974		1,550		11
1975		1,624		14
1976		1,356		12
1977		745		10
1978		402		8
1979		358		8
1980		149		9
1981		671		16
1982		834		12
1983		209		13
1984		1,788		11
	4849	128,755	40,000	6620

Table 7. Y-12 Plant liquid uranium effluents

Year	Uranium[a] (Ci)	Uranium discharges (kg)
CY 1944	22.30	33,000
1945	4.70	7,000
1946	-	-
1947	0	0
1948	0.10	155
1949	0.30	454
1950	0.10	144
1951	0.06	98
FY 1952	0.002	3
1953	0.651	953
1954	0.71	1,118
1955	0.62	1,058
1956	2.26	4,987
1957	5.65	8,448
1958	5.85	10,019
1959	5.15	10,410
1960	4.55	10,067
1961	2.00	3,064
1962	0.86	1,333
1963	0.82	1,248
1964	4.42	6,605
1965	5.91	8,852
1966	5.34	7,985
1967	10.20	15,217
1968	11.75	17,525
1969	2.80	4,189
1970	5.88	8,775
1971	2.37	3,546
1972	2.03	3,042
1973	0.74	1,119
1974	1.04	1,561
1975	1.09	1,638
1976	0.91	1,368
1977	0.50	755
1978	0.27	410
1979	0.24	366
1980	0.10	158
1981	0.45	687
1982	0.56	846
1983	0.14	222
1984	~~0.12~~ 1.20	1,799
	113.54	180,224

[a]Conversion factors used in calculating the curie values: normal uranium, 1.49×10^6 g/Ci; depleted uranium, 2.79×10^6 g/Ci; enriched uranium, 1.58×10^4 g/Ci.

Table 8. Summary of uranium effluent to water

Measured depleted uranium, 1954-1984	128,755 kg
Measured normal uranium, 1945-1953 (ref. 6)	1,738 kg
Measured normal uranium, 1953-1967 (ref. 7)	3,111 kg
Estimated normal uranium, 1944-1945 (ref. 8)	40,000 kg
Measured enriched uranium, 1949-1984 (ref. 9)	6,620 kg
Total	180,224 or rounded to 180,000 kg (396,500 lbs)

Table 9. Y-12 Plant average uranium concentration data for surface-water monitoring stations

($\times 10^{-8}$ µCi/mL)

Year	Station[a]		
	E-1[b]	B-1[c]	C-3[d]
1971	24.0	24.0	
1972	27.0	21.0	
1973	8.5	3.5	<0.2
1974	6.3	5.6	0.5
1975	6.3	5.0	0.3
1976	4.0	6.8	0.5
1977	2.3	2.9	0.3
1978	1.1	1.8	<0.1
1979	1.0	2.6	<0.2
1980	5.2	1.8	<0.09
1981	4.1	3.6	<0.1
1982	2.1	4.1	<0.13
1983	2.9	3.0	<0.17
1984	3.0	3.4	<0.55

[a]See Fig. 3.
[b]EFPC Station.
[c]Bear Creek Station.
[d]Clinch River Station (background).

Table 10. Y-12 Plant average uranium concentration data for surface-water monitoring stations as percentage of applicable DOE concentration guides

Year	Station			DOE concentration guide ($\times 10^{-8}$ µCi/mL)[d]
	E-1[a]	B-1[b]	C-3[c]	
1971	1.2	1.2		2000
1972	1.4	1.1		
1973	0.3	0.1	<0.1	4000
1974	0.2	0.2	<0.1	
1975	0.2	0.2	<0.1	
1976	0.1	0.2	<0.1	
1977	<0.1	<0.1	<0.1	
1978	<0.1	<0.1	<0.1	
1979	<0.1	<0.1	<0.1	
1980	0.2	0.1	<0.1	
1981[e]	6.8	6.0	<0.2	60
1982[e]	3.5	6.8	<0.2	
1983[e]	4.8	5.0	<0.3	
1984[e]	5.0	5.6	0.9	

[a]EFPC Station.
[b]Bear Creek Station.
[c]Clinch River Station (background).
[d]DOE concentration guides are listed in DOE Order 5480.1A, Attachment XI-1. The value of 60 x 10^{-8} µCi/mL is the lowest limit specified for uranium. Prior to 1973 a different definition of the curie was used, resulting in a different concentration guide.
[e]For 1981-1984, values for Stations E-1 and B-1 are a higher percentage of the DOE concentration due to a reduction in the guide.

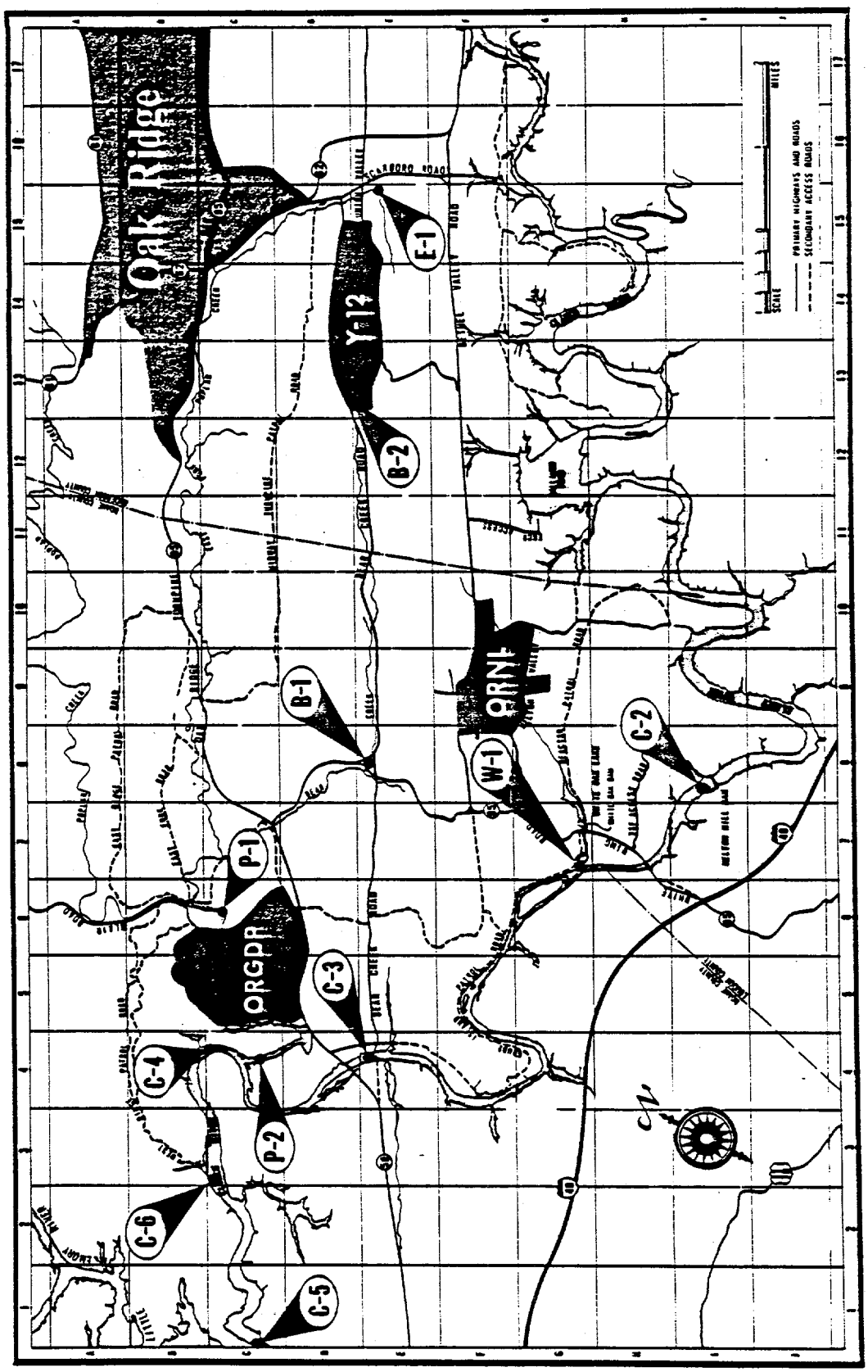

Fig. 3. Stream monitoring locations.

4.2 THORIUM

Thorium process solutions discharged to the storm sewer system originated from ORNL research programs in Y-12 and from Y-12 production programs. The discharged ORNL solution included thorium oxide slurries from corrosion testing experiments and cleanup of the pressure drop loop in ORNL Reactor Engineering. Discharges from the Y-12 production facilities came primarily from solutions generated in processing weapons parts. Some of the solutions resulted from putting salvage material in drums of water as solution was generated and held until the material was recycled (Owings, 1986).

The liquid effluents of thorium are shown in Table 11, which lists thorium discharges for the period FY 1954-1984 as recorded in accountability records. The individual fiscal-year discharge amounts are associated with calculated curie values.

Table 11. Y-12 Plant thorium liquid effluents

Fiscal year	Thorium[a] (Ci)	Thorium discharges (kg)
1954	0.001	11
1955	0.003	26
1956	0.005	44
1957	0.005	49
1958	0.008	70
1959	0.367	3363
1960	0.031	283
1961	0.101	927
1962	0	0
1963	0.002	20
1964	0.001	7
1965	-	-
1966	-	-
1967	-	-
1968	-	-
1969	-	-
1970	-	-
1971	-	-
1972	-	-
1973	-	-
1974	0.007	65
1975	0.021	195
1976	0.020	203
1977	0.019	176
1978	0.013	120
1979	0.010	93
1980	0.009	80
1981	0.009	85
1982	0.006	52
1983	0.005	49
1984	0.010	90
	0.653	6008

[a]The specific activity for Th-232 (1.09×10^{-7} Ci/g) was used in calculating the curies per year.

5. Y-12 PLANT RADIOACTIVE SOLID WASTE DISPOSAL DATA

5.1 URANIUM

The radioactive solid waste generated by Y-12 Plant operations include essentially uranium and uranium-contaminated materials. The uranium wastes include depleted uranium metals and oxides in the form of chips, turnings, sawfines, powders, bulk scrap, and process residue contaminated with depleted uranium. The process residue includes gloves, floor sweepings, filters, equipment, scrap metal, debris, and demolition debris. In addition to depleted uranium wastes, the Plant generates a quantity of enriched uranium-contaminated process wastes which are discarded after economic recovery of the enriched uranium. Most of the solid wastes have been buried in the Bear Creek Burial Ground. Remaining wastes have been deposited in burial areas within the Plant perimeter fence and along Chestnut Ridge.

In addition to the solid wastes, uranium-contaminated liquid wastes such as oils, solvents, and mop waters were discarded to the Bear Creek Burial Ground until the 1970s. By 1979, only waste solvents were being discarded to the Burial Ground. In 1982 the disposal of all liquids was terminated at the Bear Creek Burial Ground.

Since 1983 only solid uranium or uranium-contaminated wastes have been placed in this burial ground. The majority of the uranium buried is depleted uranium metal chips. At the main plant, the depleted uranium metal chips are placed in a dumpster that contains a quantity of water to prevent spontaneous burning of uranium (uranium metal is pyrophoric). The dumpster is then weighed and the uranium and water are placed in narrow trenches 6 to 18 m (20 to 60 ft) long. After the trenches are filled, soil is placed on top of the uranium. The uranium weights are sent to NMC&A and then to Idaho Falls, where an annual report is issued as the DOE SWIMS report. Because the depleted uranium and the water are weighed together and reported as all uranium, the accounting bias shows a gain of 1,499,155 kg of depleted uranium for the period from 1947 to 1984. This means the SWIMS report numbers are biased high.

In addition to the chip disposals, uranium-contaminated material (wood, metal, etc.) is delivered several times daily by dump trucks from the operating buildings with a minimum of 6 yd^3 (4.6 m^3) of material in each load. This material is placed in the burial ground. For the uranium-contaminated wastes, an estimated weight of the gross volume of waste is recorded in disposal records, which becomes part of the SWIMS report but not of the accountability records.

Uranium solid wastes comprise a great variety of material types and configurations and an extremely large number of batches during any particular year of processing. Because of these and other characteristics, it is not possible to accurately account through measurement for all uranium so disposed of. Even though wastes can be weighed in most cases, chemical analyses showing the uranium content are

seldom possible. The measurements used to determine annual inventories are inherently more accurate than those used for waste disposal. For these reasons a more accurate method of indicating quantities buried would be to correct the discards by the accounting bias.

The accounting bias for depleted uranium has traditionally been gains (resulting from inflated values for solid disposal). Therefore, the quantities of uranium indicated to be buried have been corrected based on the biases from accountability records. Applying these corrections on an annual basis to the historical data does result in the data showing gains instead of losses to the burial ground for a number of years (these are denoted by parentheses in Tables 12 and 13). This does not mean that material was removed from the burial ground, but that the values are really part of a prior or succeeding year's inventory. The simplest way to make this bias correction for buried wastes would be to apply it to the 40-year cumulative values. However, in order to reflect the historical activities on an annual basis the values are also shown in annual tabulations.

Solid waste disposal data are shown in Tables 12 through 14. Table 12 shows depleted, normal, and enriched uranium as measured amounts. Table 13 lists uranium discharges by fiscal year associated with calculated values for curies. Table 14 shows the summary of all uranium buried for the period 1944-1984. The total uranium buried at Y-12 is estimated at 16,000,000 kg (35,000,000 lbs).

Table 12. All uranium discards to burial ground

Year	Measured depleted (kg)	Measured normal (kg)	Measured ENR <20% (kg)	Measured ENR >20% (kg)
1944	-	-	(33)	-
1945	-	-	(255)	-
1946	-	-	-	(209)
1947	21	(411)	41	(22)
1948	3	131	69	0
1949	(205)	29	18	2
1950	(1)	248	10	(1)
1951	0	657	6	(1)
1952	0	1,428	37	1
1953	(30)	(575)	(20)	1
1954	2,236	46	1	10
1955	21,770	17	1	18
1956	22,448	485	(4)	28
1957	37,554	474	186	39
1958	(9,225)	(128)	5513	77
1959	20,224	(21)	1569	159
1960	202,061	2,511	2077	119
1961	1,490,076	1,473	267	79
1962	198,261	1,269	88	126
1963	325,918	11	(33)	(53)
1964	676,745	30	66	147
1965	375,762	71	2	6
1966	1,295,200	1,834	82	144
1967	978,589	1,376	(1)	(56)
1968	236,674	1,090	30	42
1969	389,493	567	4	9
1970	645,872	(9)	0	77
1971	556,159	87	(3)	(1)
1972	996,994	1,176	20	159
1973	761,269	420	(26)	66
1974	613,653	743	(1)	11
1975	540,692	(39)	1	35
1976	455,401	1,838	2	49
1977	(45,098)	10,151	327	58
1978	842,670	46	558	2
1979	11,240	345	683	56
1980	529,091	293	126	7
1981	703,129	247	144	81
1982	1,169,135	335	243	52
1983	809,217	515	6	52
1984	943,495	(159)	(2)	53
	15,796,493	28,601	11,799	1422

Table 13. Y-12 Plant uranium contained in solid waste buried on-site

Year	Uranium (Ci)	Uranium discharged (kg)
CY 1944	(2.09)	(33)
1945	(16.14)	(255)
1946	(13.23)	(209)
1947	0.93	(371)
1948	4.46	203
1949	1.22	(156)
1950	0.74	256
1951	0.76	662
FY 1952	3.05	1,466
1953	(1.30)	(624)
1954	1.53	2,293
1955	9.04	21,806
1956	9.92	22,957
1957	420.78	38,253
1958	(42.32)	(3,763)
1959	116.63	21,931
1960	213.36	206,768
1961	558.89	1,491,895
1962	85.71	199,744
1963	111.81	325,843
1964	243.43	676,988
1965	135.73	375,841
1966	481.43	1,297,260
1967	349.32	979,908
1968	90.42	237,836
1969	141.31	390,073
1970	237.19	645,940
1971	199.87	556,242
1972	370.75	998,349
1973	276.65	761,729
1974	221.87	614,406
1975	196.74	540,689
1976	168.27	457,290
1977	(15.10)	(34,562)
1978	368.65	843,276
1979	51.04	12,324
1980	198.94	529,517
1981	267.33	703,601
1982	439.44	1,169,765
1983	295.11	809,790
1984	342.51	943,387
	6524.65	15,838,315

Table 14. Summary of uranium discards to burial ground[a]

Record of uranium buried	17,859,645 kg
Bias high (water)	1,499,155 kg
Total uranium	16,360,490 kg
Uranium transported to X-10 site	522,175 kg[b]
Total uranium buried	15,838,315 or rounded to 16,000,000 kg (35,000,000 lbs)

[a]Prior to 1972, liquid material containing uranium that was transferred from operation, off-site, etc., to the S-3 Ponds was included in accountability records and considered as solid uranium in the burial ground. The values appear in Tables 12 and 13.

[b]By U.S. Nuclear Regulatory Commission (NRC)/DOE transfer documents.

5.2 URANIUM AS U-233

During FY 1967 and 1968, research and development work was being done on U-233 material at Y-12. In the fabrication of the U-233 parts, turnings, combustibles, oxides, and various types of salvage and scrap were generated. Scrap metal was cleaned and recast; however, some salvage materials were discarded to the Y-12 burial ground and recorded in accountability records. Table 15 shows the estimated amount of U-233 associated with the salvage materials discarded (FY 1967-1968) and the calculated curie values.

Table 15. Y-12 Plant U-233 contained in solid waste buried on-site

Fiscal year	U-233[a] (Ci)	U-233 discharges (kg)
1967	9.48	1
1968	9.48	1
	18.96	2

[a]Specific activity used in calculating curie content was 9.48×10^{-3} Ci/g.

5.3 THORIUM

Thorium process residues disposed to the burial ground originated from ORNL research in Y-12 and from Y-12 production programs. The thorium solid residues included scrap metal, oxides, turnings, sawfines, and contaminated process residue. The process residue included filters, floor sweepings, gloves, equipment, and debris. In addition to the thorium wastes, Y-12 discarded 64,229 kg of scrap metal in FY 1983 that had been in storage for several years awaiting recovery. In FY 1982 it was decided that the thorium scrap was no longer needed to meet production and research schedules, so it was discarded to the burial ground.

The solid thorium discharges are shown in Table 16. This table lists discharges for the period 1947-1984. The individual yearly discharge amounts are associated with calculated curie values.

5.4 HISTORIC NONACCOUNTABLE RADIONUCLIDES RELEASED

Table 17 summarizes historic nonaccountable radionuclides (in grams) contained in waste buried on-site for which quantitative values could be determined. This table of radionuclides is primarily associated with reactor product uranyl nitrate solutions and oxides received from the Savannah River and Idaho Operations Offices. Reactor receipts began in FY 1953.

Data records from NMC&A, Health Physics, various operation groups, and the Plant Laboratory were used to generate Table 17.

The assumptions used for these estimates (because only limited measurements were made for contamination control purposes either on solution or oxide receipts and on metal returned to SRP) were as follows.

1. All metal shipped to SRP until 1953 was from routine production.

2. Y-12 recovery of uranyl nitrate solutions and oxide through organic extraction resulted in a 15-to-1 decontamination factor for fission products (FP) and transuranics.

3. The portion of the FP and transuranics remaining at Y-12 was concentrated in the raffinates that ended up as a discharge to S-3 Ponds and was included in the records as burial.

4. The portion of the FP and transuranics remaining in the purified product was returned to SRP in the recycle-metal stream.

Also, the values in Table 17 represent the total radionuclide estimated to have remained at Y-12. To allow for the greatest environmental impact, it is assumed that all of these amounts were released to the environment. Releases of Tc-99 and Np-237 are shown on Tables 18 and 19 respectively. Both elements are listed with releases for the period FY 1953-1984. The individual yearly releases in the tables are associated with calculated curie values.

Table 16. Y-12 Plant thorium contained in solid waste buried on-site

Year	Thorium[a] (Ci)	Thorium discharges (kg)
CY 1947	0.0001	1
1948	0	0
1949	0	0
1950	0.0001	1
1951	0	0
FY 1952	0.0002	2
1953	0	0
1954	0.0005	5
1955	0.0004	4
1956	0.001	11
1957	0.0007	6
1958	0.001	12
1959	0.062	565
1960	0.017	159
1961	0.103	948
1962	0.342	3,142
1963	0.560	5,142
1964	1.562	14,329
1965	2.076	19,042
1966	0.607	5,573
1967	0.645	5,914
1968	0.152	1,398
1969	0.173	1,587
1970	1.050	9,633
1971	0.953	8,743
1972	1.052	9,655
1973	0.822	7,541
1974	0.012	111
1975	0.434	3,981
1976	0.388	3,564[b]
1977	0.194	1,780
1978	0.014	131
1979	0.056	515
1980	0.056	514
1981	0.023	215
1982	0.023	216
1983	7.001	64,229
1984	0.011	101
	18.392	168,770

[a]The specific activity used in calculating the thorium curie content was that of Th-232 (1.09×10^{-7} Ci/g).

[b]The quantity shown for 1976 does not include 276 kg thorium placed in the Y-12 burial ground at the request of the State of Tennessee as a result of cleanup of Nuclear Chemicals and Metals Corp. (FCY) at Huntsville, Tennessee.

Table 17. Historic nonaccountable radionuclides released[a]

	Calculated values (Ci)	Burial (g)
Cesium-137	<43.50	<0.5
Cobalt-57/60	9620	2
Neptunium-237	1.60	2400
Niobium-95	<19,600	<0.5
Plutonium-238/239	26.19	3
Ruthenium-106	<1.68	<0.5
Technetium-99	53.60	3000[b]
Thorium-228	<410.50	<0.5
Zirconium-95	<10,500	<0.5

[a]Annual data only shown for technetium and neptunium (refer to Tables 18 and 19).

[b]Includes 600 g disposed to Y-12 burial ground from the K-25 site.

Table 18. Y-12 Plant technetium contained in solid waste buried on-site

Fiscal year	Technetium[a] (Ci)	Technetium discharges (g)
1953	0.07	4
1954	0.21	12
1955	0.29	16
1956	0.29	16
1957	1.50	84
1958	1.50	84
1959	1.50	84
1960	1.50	84
1961	1.50	84
1962	1.50	84
1963	1.50	84
1964	1.50	84
1965	1.50	84
1966	1.50	84
1967	1.50	84
1968	1.50	84
1969	1.50	84
1970	1.50	84
1971	1.50	84
1972	1.50	84
1973	1.50	84
1974	1.50	84
1975	1.50	84
1976	1.50	84
1977	3.29	184
1978	3.29	184
1979	3.29	184
1980	3.29	184
1981	3.29	184
1982	3.29	184
1983	1.50	84
1984	1.50	84
	53.60	3000

[a]The specific activity used in calculating the curie values for Tc-99 was 1.79×10^{-2} Ci/g.

Table 19. Y-12 Plant neptunium contained in solid waste buried on-site

Fiscal year	Neptunium[a] (Ci)	Neptunium discharges (g)
1953	0.05	75
1954	0.05	75
1955	0.05	75
1956	0.05	75
1957	0.05	75
1958	0.05	75
1959	0.05	75
1960	0.05	75
1961	0.05	75
1962	0.05	75
1963	0.05	75
1964	0.05	75
1965	0.05	75
1966	0.05	75
1967	0.05	75
1968	0.05	75
1969	0.05	75
1970	0.05	75
1971	0.05	75
1972	0.05	75
1973	0.05	75
1974	0.05	75
1975	0.05	75
1976	0.05	75
1977	0.05	75
1978	0.05	75
1979	0.05	75
1980	0.05	75
1981	0.05	75
1982	0.05	75
1983	0.05	75
1984	0.05	75
	1.60	2400

[a]The specific activity used in calculating the curie values for Np-237 was 7.1×10^{-4} Ci/g.

1985 0.05 75

1986 0.05 75

6. RADIATION EXPOSURE CALCULATIONS AND ESTIMATED HUMAN HEALTH IMPACT

The calculation of potential radiation dose to the public requires the use of models of various degrees of complexity that represent the movement of radioactive materials through the environment from the source to humans. These models have to take into account the nature and physical and chemical characteristics of the radioactive materials, as well as of their methods of release. The models then have to reflect the characteristics of the environment and of humans that influence the consequent exposure of individuals and groups.[10]

The doses received by a tissue or organ from various pathways (internal and external) are weighed and then summed to estimate the effective dose. This assumes that (1) a linear relationship (without threshold) exists between dose and the probability of an effect and (2) the severity of each type of effect is independent of dose. These assumptions are based on the recommendations of the International Commission on Radiological Protection (ICRP).[10]

The ICRP had formerly recommended that when one or more than one organ of the body is exposed, the irradiation of one particular organ or tissue is likely to be of greatest importance because of (1) the dose it received, (2) its sensitivity to radiation, or (3) the importance to health of any damage that results. This tissue or organ was referred to as the "critical organ." The ICRP now recommends a procedure that takes into account the total risk attributable to the exposure of all tissues irradiated. This dose is now referred to as the "effective dose equivalent."

For the purposes of this report, the total radiation exposure of all residents within a 24- and 80-km (15- and 50-mile) radius of the Y-12 Plant has been calculated based on total emissions recorded from 1944 through 1984. Table 20 evaluates the human health impacts from these releases. These data indicate a total of 11,377 person-rems effective dose for an 80-km (50-mile) radius and 5790 person-rems effective dose for a 24-km (15-mile) radius from the Y-12 Plant. This compares to the expected total population effective dose of 4.9 million person-rems from natural sources of radiation in the same 80-km (50-mile) radius and approximately 800,000 person-rems from natural sources of radiation for the 24-km (15-mile) radius. Potential health effects were estimated by multiplying the total population dose of 11,377 person-rems effective 40-year dose by 1.65×10^{-4} health effects per person-rem. The resulting estimate indicates a 1.8 health effect above normal environmental background. This means that releases from the Y-12 Plant could result in 1.8 health effects within an 80-km (50-mile) radius of the plant.

Table 20. Health effects from Y-12 releases of uranium, 1944-1984

	Population within 80 km (50 miles)
Average annual dose[a] (person-rem)	285
Percent of background (%)	0.16
Accumulated dose, 40 years (person-rem)	11,377
Health effects	1.8
	Population within 23 km (15 miles)
Average annual dose (person-rem)	145
Percent of background (%)	0.31
Accumulated dose, (40 years) (person-rem)	5790
Health effects	0.95

[a]All doses are effective total body dose equivalents.

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REFERENCES

1. Includes accidental release of 42 kg enriched uranium from 1956 through 1959 from operating buildings (accountability records).

2. G. Wimpsett, *Uranium Gas Release,* Y-1253, Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant, June 1985.

3. J. R. Barkman et al., "Investigation Committee Report on Level 2 Criticality Safety Violation," letter to R. D. Williams, May 18, 1983.

4. Laboratory Notebook No. Y/NB/5007, "Classified Data for Tennessee Air Pollution Control Permits," Apr. 23, 1985.

5. "Pilot-Scale Collection and Recovery of Airborne Tuballoy in Operating Buildings," Report G-1.133.3, Nov. 19, 1945.

6. Y-12 Plant Health Physics Reports

   1948: Y-181, Y-215, Y-257, Y-280, Y-300, Y-318;
   1949: Y-339, Y-365, Y-402;
   1950: Y-780;
   1951: Y-836, Y-858;
   1953: Y-1074.

7. Accountability records of operational discharge to the storm sewer water systems, 3111 kg of normal uranium, for 1953-1967.

8. Inventory of "Alpha Buildings" uranium, December 1946; summary of operations from Aug. 12, 1943 to Dec. 31, 1946.

9. Accountability records of measured enriched uranium discharge from operating building to the water system for 1949-1984.

10. *Recommendations of the International Commission on Radiological Protection,* ICRP Publication 26, Pergamon Press, New York, 1977.

BIBLIOGRAPHY

1. T. R. Butz, *Y-12 Plant Uranium Discharges (U)*, Y/TS-105, Rev. 1, Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant, June 1985.

2. T. E. Koprowski, *Y-12 Plant Uranium Discharges (U)*, K/PD-38, Martin Marietta Energy Systems, Inc., Oak Ridge Gaseous Diffusion Plant, January 1986.

3. E. Owings, W. B. Kenna, and M. S. Franklin, *Historic Accountable Radionuclide Releases (U)*, Y/DG-17574, Rev. 1, Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant, September 1985.

4. U.S. Environmental Protection Agency, NESHAPS, *Radionuclides: Background Information Document for Final Rules*, EPA 520/1-84-022-1, Washington, D.C., 1985.

5. *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 30, Pergamon Press, New York, 1978.

6. *Metabolism of Plutonium and Other Actinides*, ICRP Publication 19, Report of Committee II, Pergamon Press, London, 1975.

7. *Report on Reference Man*, ICRP Publication 23, Report of ICRP Task Group, W. S. Snyder, Chairman, Pergamon Press, London, 1975.

8. G. J. Hine and G. L. Brownell, eds., *Radiation Dosimetry*, Academic Press, London, 1972.

9. K. Z. Morgan and J. E. Turner, eds., *Principles of Radiation Protection*, Wiley, New York, 1967.

10. W. S. Snyder et al., "Calculations of Absorbed Dose to a Man Immersed in an Infinite Cloud of Krypton-85," presented at the Noble Gases Symposium, Las Vegas, Sept. 24, 1973.

11. W. D. Turner, S. V. Kaye, and P. S. Rohwer, *EXREM and INREM Computer Codes for Estimating Radiation Dose to Populations from Construction of a Sea-Level Canal with Nuclear Explosives*, K-1752, CTC, and Oak Ridge Natl. Lab., Oak Ridge, Tennessee, September 1968.

12. D. K. Trubey and S. V. Kaye, *The EXREM III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases*, ORNL/TM-4322, Oak Ridge Natl. Lab., December 1973.